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METHOD AND SYSTEM FOR AUTOMATIC IMAGE ADJUSTMENT FOR IN VIVO IMAGE DIAGNOSIS

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METHOD AND SYSTEM FOR AUTOMATIC IMAGE ADJUSTMENT FOR IN VIVO IMAGE DIAGNOSIS

FIELD OF THE INVENTION

The present invention relates generally to an endoscopic imaging system and, in particular, to image exposure adjustment of in vivo images.

BACKGROUND OF THE INVENTION

Several in vivo measurement systems are known in the art. They include swallowed electronic capsules which collect data and which transmit the data to an external receiver system. These capsules, which are moved through the digestive system by the action of peristalsis, are used to measure pH ("Heidelberg" capsules), temperature ("CoreTemp" capsules) and pressure throughout the gastro-intestinal (GI) tract. They have also been used to measure gastric residence time, which is the time it takes for food to pass through the stomach and intestines. These capsules typically include a measuring system and a transmission system, wherein the measured data is transmitted at radio frequencies to a receiver system.

U.S. Patent No. 5,604,531, assigned to the State of Israel, Ministry of Defense, Armament Development Authority, and incorporated herein by reference, teaches an in vivo measurement system, in particular an in vivo camera system, which is carried by a swallowed capsule. In addition to the camera system there is an optical system for imaging an area of the GI tract onto the imager and a transmitter for transmitting the video output of the camera system. The capsule is equipped with a number of LEDs (light emitting diodes) as the lighting source for the imaging system. The overall system, including a capsule that can pass through the entire digestive tract, operates as an autonomous video endoscope. It images even the difficult to reach areas of the small intestine.

U.S. Patent Application No. 2003/0023150 A1, assigned to Olympus Optical Co., LTD., and incorporated herein by reference, teaches a design of a swallowed capsule-type medical device which is advanced through the inside of the somatic cavities and lumens of human beings or animals for

conducting examination, therapy, or treatment. Signals including images captured by the capsule-type medical device are transmitted to an external receiver and recorded on a recording unit. The images recorded are retrieved in a retrieving unit, displayed on the liquid crystal monitor and to be compared by an endoscopic examination crew with past endoscopic disease images that are stored in a disease image database.

One problem associated with the capsule imaging system is a non-uniform lighting over the imaging area due to the nature of this miniature device. Especially, when the capsule travels along a tube-like anatomical structure, the field of view of the camera system covers a section of the anatomical structure inner wall which is nearly parallel with the camera optical axis. Obviously, in this field of view, part of the anatomical structure inner wall away from the capsule receives less photon flux than that of the anatomical structure inner wall close to the capsule. The resultant is a non-uniform photon flux field. In return, part of the image produced by the camera image sensor is either under exposure or over exposure depends on how the camera is calibrated. Therefore, details of texture and color will be lost, which not only affects physicians' ability of abnormality diagnosis using these in vivo images, but also reduces the effectiveness of neighboring in vivo image stitching in applications such image mosiacing.

In general, in order to maximize the use of photon flux, the in vivo camera is calibrated such that there will be no over exposure in the captured images. Thus the non-uniform photon flux distribution results in under exposure in various areas of certain in vivo images. This under exposure of in vivo image is similar to the light falloff in regular photographic images.

U.S. Patent Application No. 2003/0007707 A1, assigned to Eastman Kodak Company, and incorporated herein by reference, teaches a method for compensating for light falloff caused by the non-uniform exposure which is produced by lenses at their focal plane when imaging a uniformly lit surface. For instance, the light from a uniformly gray wall perpendicular to the camera optical axis will pass through a lens and form an image that is brightest at the center and dims radially. When the lens is an ideal thin lens, the intensity of light in the

image will form an intensity pattern described by $\cos^4$ of the angle between the optical axis of the lens and the point in the image plane. The visible effect of this phenomenon is referred to as falloff. The light compensating method taught in 0007707 describes a compensation function that relies on the value of the distance from a pixel location to the center of the image. Such a method is particularly useful for falloffs caused by lenses distortions. Invention 0007707 teaches a compensation equation: $fcm(x,y) = \frac{4 * cvs}{\log 2} \log(\cos(\tan^{-1}(\frac{dd}{f})))$. Where *dd* is the distance in pixels from the (x,y) position to the center of the digital image and *cvs* is the number of code value per stop of exposure (*cvs* indicates scaling of the log exposure metric). The parameter *f* represents the focal length of a lens (in pixels) for which the falloff compensator will correct the falloff. This method is however less desirable for problems caused by non-uniform photon flux field when the endoscopic capsule traveling alone the GI tract, because regions with inadequate exposure do not have the geometric properties stated in the aforementioned equation.

Also the principal advantage of the invention described in 0007707 is that a falloff compensation may be applied to a digital image in such a manner that the balance of the compensated digital image is similar to that of the original digital image, which results in a much more pleasing effect that sometimes may causing problems such as blurring boundaries.

There is a need therefore for an improved endoscopic imaging system that overcomes the problems set forth above.

These and other aspects, objects, features and advantages of the present invention will be more clearly understood and appreciated from a review of the following detailed description of the preferred embodiments and appended claims, and by reference to the accompanying drawings.

SUMMARY OF THE INVENTION

The need is met according to the present invention by providing a digital image processing method for exposure adjustment of in vivo images that

includes the steps of acquiring in vivo images; detecting any crease feature found in the in vivo images; preserving the detected crease feature; and adjusting exposure of the in vivo images with the detected crease feature preserved.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 (PRIOR ART) is a block diagram illustration of an in vivo camera system.

FIG. 2A is an illustration of the concept of an examination bundle of the present invention.

FIG. 2B is an illustration of the concept of an examination bundlette of the present invention.

FIG. 3A is a flowchart illustrating information flow of the real-time abnormality detection method in the copending application.

FIG. 3B is a flowchart illustrating information flow of the in vivo image adjustment for diagnosis of the present invention.

FIG. 4 is a schematic diagram of an examination bundlette processing hardware system useful in practicing the present invention.

FIG. 5 is a flowchart illustrating the in vivo image adjustment method of the present invention.

FIG. 6 is a flowchart illustrating the exposure correction and cross boundary smoothing method of the present invention.

FIG. 7A is a schematic diagram of a binary image.

FIG. 7B is a schematic diagram of a mask image.

FIG. 7C is a schematic diagram of a skeleton image.

FIG. 7D is a schematic diagram of a binary image.

FIG. 8 is a collection of patterns.

FIG. 9A is a schematic diagram of an intermediate mask image.

FIG. 9B is a schematic diagram of a mask image.

FIG. 10A is a schematic diagram of a smoothing band image.

FIG. 10B is a schematic diagram of a one dimensional line in the smoothing band.

DETAILED DESCRIPTION OF THE INVENTION

In the following description, various aspects of the present invention will be described. For purposes of explanation, specific configurations and details are set forth in order to provide a thorough understanding of the present invention. However, it will also be apparent to one skilled in the art that the present invention may be practiced without the specific details presented herein. Furthermore, well-known features may be omitted or simplified in order not to obscure the present invention.

During a typical examination of a body lumen, the in vivo camera system captures a large number of images. The images can be analyzed individually, or sequentially, as frames of a video sequence. An individual image or frame without context has limited value. Some contextual information is frequently available prior to or during the image collection process; other contextual information can be gathered or generated as the images are processed after data collection. Any contextual information will be referred to as metadata. Metadata is analogous to the image header data that accompanies many digital image files.

FIG. 1 shows a block diagram of the in vivo video camera system described in U.S. Patent No. 5,604,531. The system captures and transmits images of the GI tract while passing through the gastro-intestinal lumen. The system contains a storage unit **100**, a data processor **102**, a camera **104**, an image transmitter **106**, an image receiver **108**, which usually includes an antenna array, and an image monitor **110**. Storage unit **100**, data processor **102**, image monitor **110**, and image receiver **108** are located outside the patient's body. Camera **104**, as it transits the GI tract, is in communication with image transmitter **106** located in capsule **112** and image receiver **108** located outside the body. Data processor **102** transfers frame data to and from storage unit **100** while the former analyzes the data. Processor **102** also transmits the analyzed data to image monitor **110** where a physician views it. The data can be viewed in real time or at some later date.

Referring to Figure 2A, the complete set of all images captured during the examination, along with any corresponding metadata, will be referred to as an examination bundle **200**. The examination bundle **200** consists of a collection of image packets **202** and a section containing general metadata **204**.

An image packet **206** comprises two sections: the pixel data **208** of an image that has been captured by the in vivo camera system, and image specific metadata **210**. The image specific metadata **210** can be further refined into image specific collection data **212**, image specific physical data **214** and inferred image specific data **216**. Image specific collection data **212** contains information such as the frame index number, frame capture rate, frame capture time, and frame exposure level. Image specific physical data **214** contains information such as the relative position of the capsule when the image was captured, the distance traveled from the position of initial image capture, the instantaneous velocity of the capsule, capsule orientation, and non-image sensed characteristics such as pH, pressure, temperature, and impedance. Inferred image specific data **216** includes location and description of detected abnormalities within the image, and any pathologies that have been identified. This data can be obtained either from a physician or by automated methods.

The general metadata **204** contains such information as the date of the examination, the patient identification, the name or identification of the referring physician, the purpose of the examination, suspected abnormalities and/or detection, and any information pertinent to the examination bundle **200**. It can also include general image information such as image storage format (e.g., TIFF or JPEG), number of lines, and number of pixels per line.

Referring to Fig. 2B, the image packet **206** and the general metadata **204** are combined to form an examination bundlette **220** suitable for real-time abnormality detection.

It will be understood and appreciated that the order and specific contents of the general metadata or image specific metadata may vary without changing the functionality of the examination bundle.

Referring now to Fig. 3A, an exemplary application of the capsule in vivo imaging system is described. Fig. 3 is a flowchart illustrating a real-time automatic abnormality detection method of the present invention. In Fig. 3A, an in vivo imaging system **300** can be realized by using systems such as the swallowed capsule described in U.S. Patent No. 5,604,531 for the present invention. An in vivo image **208** is captured in an in vivo image acquisition step **302**. In a step of In Vivo Examination Bundlette Formation **304**, the image **208** is combined with image specific data **210** to form an image packet **206**. The image packet **206** is further combined with general metadata **204** and compressed to become an examination bundlette **220**. The examination bundlette **220** is transmitted to a proximal in vitro computing device through radio frequency in a step of RF transmission **306**. An in vitro computing device **320** is either a portable computer system attached to a belt worn by the patient or in near proximity. Alternatively, it is a system such as shown in Fig.4 and will be described in detail later. The transmitted examination bundlette **220** is received in the proximal in vitro computing device in a step of In Vivo RF Receiver **308**.

Data received in the in vitro computing device is examined for any sign of disease in a step of Abnormality detection **310**. Details of the step of abnormality detection can be found in commonly assigned, co-pending U.S. Patent Application Serial No. 10/679,711, entitled "Method And System For Real-Time Automatic Abnormality Detection For In Vivo Images" and filed on 06 October 2003 in the names of Shoupu Chen, Lawrence A. Ray, Nathan D. Cahill and Marvin M. Goodgame, and which is incorporated herein by reference.

Note that unlike taking photographic images in natural scenes (indoor or outdoor), in vivo imaging takes place inside the GI tract which is a controlled environment and in general is an open space within the field of the view of the camera. A controlled environment means that there are no sources of lighting other than that from the LEDs of the capsule. An open space implies that there should be no occlusions that cause shadows (under exposure). Also, the reflectance should be the same locally along the GI tract inner wall in general, at least with the same order of magnitude. (This is not the case in real world where

the reflectance of photographic objects could vary dramatically causing darker or brighter areas in the resultant images.) Thus, in an ideal case, an in vivo image should not present significant brightness differences in different areas. In reality, because of the uneven photon flux field generated by the limited lighting source, under exposure areas (low brightness areas) exist. Those low brightness areas need to be corrected to become brighter. While in photographic images of natural scenes (indoor or outdoor), low brightness areas could be a result of low reflection of a dark object surface which should not be corrected in an image.

Fig. 3B shows a diagram of information flow of the present invention. To ensure an effective detection and diagnosis of abnormality, images from RF Receiver **308** are exposure adjusted in a step of Image adjusting **309** before the abnormality detection **310** takes place (see Fig. 3B).

The step of Image adjusting **309** is detailed in Fig. 5. Denote image **501** received from RF receiver **308** by **I** and its pixel by $\mathbf{I}(m,n)$, where $m = 0,...M-1$, $n = 0,...N-1$, M is the number of rows, and N is the number of columns. To automatically find if an image has under exposure regions, a step of image thresholding **502** is utilized. A threshold T (**505**) is established through a supervised learning. A supervised learning here means learning in vivo image characteristics by applying statistical analysis to a large number of in vivo images. Statistical analysis includes mean or median intensity analysis, and intensity deviation *etc.* An exemplary threshold value could be $T = mean(\mathbf{I}) - K * std(\mathbf{I})$ where $mean(\mathbf{I})$ returns mean brightness value of the image, $std(\mathbf{I})$ returns the standard deviation value of the image, and K is a coefficient. An exemplary value of K is 3. The output of step **502** is a threshold image $\mathbf{I}_B$ and its pixel is expressed as $\mathbf{I}_B(m,n)$. If a pixel value at location (m,n) is less than T (**505**), then $\mathbf{I}_B(m,n) = 1$, otherwise, $\mathbf{I}_B(m,n) = 0$.

Fig. 7A shows an exemplary threshold image $\mathbf{I}_B$ (**702**). The value of pixels $\mathbf{I}_B(m,n)$ in regions **704**, and **706** are one indicating that corresponding pixels, $\mathbf{I}(m,n)$, in image **I** have lower brightness value than T (**505**). Note that image $\mathbf{I}_B$ **702** displays exemplary one-valued regions **706** indicating the

corresponding low brightness areas in image **I (501)** caused by crease features where light rays are unable to reach directly in certain anatomical structures of the GI tract. Image $\mathbf{I}_B$ **702** also displays exemplary one-valued region **704** indicating a low brightness area in image **I (501)** caused mainly by the non-uniform photon flux field. The low brightness area in image **I (501)** corresponding to region **704** is subject to image adjustment to lift the brightness level for better diagnosis.

There are variety methods could be used to lift the brightness of an under exposure area in image **I (501)**. A preferred algorithm is described below.

Referring back to Fig. 5, in a step of Forming mask A **(506)**, the threshold image $\mathbf{I}_B$ **(702)** undergoes a morphological opening process to close holes and gaps. The resultant image is named as mask A **(712)** shown in Fig. 7B, and denoted by $\mathbf{I}_{MA}$ and its pixel by $\mathbf{I}_{MA}(m,n)$. In a step of Image statistics gathering **508**, the following equation is used to get ***statsA*** **(503)**:

$$statsA = F(\mathbf{I} \cap \bar{\mathbf{I}}_{MA}) \qquad \textbf{(1)}$$

where $\mathbf{I} \cap \bar{\mathbf{I}}_{MA}$ is a logical AND operation, $\bar{\mathbf{I}}_{MA}$ is the logical inverse of $\mathbf{I}_{MA}$, $F(\bullet)$ is a statistical analysis operation, and ***statsA*** **(503)** is a **structure** containing mean, median and other statistical quantities of the operand which is the result of the logical AND operation, $\mathbf{I} \cap \bar{\mathbf{I}}_{MA}$. The **structure** is a C language like data type and ***statsA*** **(503)** is defined as

structure *stats*
{
    mean;
    median;
    minimum;
    maximum;
} ***statsA***

where *stats* is the **structure** name and ***statsA***.mean is the mean intensity of $\mathbf{I} \cap \bar{\mathbf{I}}_{MA}$, ***statsA***.median is the median intensity of $\mathbf{I} \cap \bar{\mathbf{I}}_{MA}$, ***statsA***.minimum is the minimal intensity of $\mathbf{I} \cap \bar{\mathbf{I}}_{MA}$ and ***statsA***.maximum is the maximal intensity of $\mathbf{I} \cap \bar{\mathbf{I}}_{MA}$.

Note that the logical AND operation, $\mathbf{I} \cap \bar{\mathbf{I}}_{MA}$, excludes under exposure pixels in the original image $\mathbf{I}$ **(501)** from the statistical analysis operation $F(\bullet)$. The purpose of this exclusion is to learn the statistics only in the normal exposure regions and the learned statistics will be used in a later procedure to lift the brightness level of under exposure regions so that the final image appears coherent.

Since the image adjustment operation is only applied to regions of under exposure (such as **704**) caused by the non-uniform photon flux field, a second mask needs to be formed to exclude low brightness regions (such as **706**) that belong to crease features. The second mask, mask B, is formed in a step of Forming mask B (**504**). The step of Forming mask B (**504**) is further detailed next.

A first operation of forming mask B (**504**) is a medial axis transformation that is applied to the threshold image $\mathbf{I}_B$ **(702)** (see "Algorithm for image processing and computer vision", by J.R. Parker, Wiley Computer Publishing, John Wiley & Sons, Inc., 1997). A medial axis transformation defines a unique compressed geometrical representation of an object. The medial axis transformation is also referred to as morphological skeletonization. The morphological skeletonization uses erosion and opening as basic operations. The result of the morphological skeletonization is a skeleton image. Denote the skeleton image by $\mathbf{I}_S$ and its pixel by $\mathbf{I}_S(m,n)$. Then $\mathbf{I}_S(m,n) = S(\mathbf{I}_B(m,n))$, where S is the medial axis transformation function. $\mathbf{I}_S(m,n)$ **(722)**, an exemplary result of applying the medial axis transformation to image $\mathbf{I}_B$ **(702)**, is shown in Fig. 7C. Note that the thick lines **706** in Fig. 7A become one-valued thin lines **726** in Fig. 7C. The one-valued region **704** in Fig. 7A becomes a set of one-valued thin lines **724**. Note also that lines **724**, and **726** have a width of one pixel. Obviously, every pixel on lines **724**, and **726** in image $\mathbf{I}_S$ must have a corresponding pixel on lines **704** and **706** in image $\mathbf{I}_B$. For lines such as **706**, their skeleton lines **726** are medial axes of their own. For regions such as **704**, in general, they have a set of skeleton lines **724**. The skeleton lines are used to detect crease features in the

threshold image. The skeleton lines also guide an erasing operation described below.

Denote the second mask, mask B, by $\mathbf{I}_{MB}$ and its pixel by $\mathbf{I}_{MB}(m,n)$. First, initialize $\mathbf{I}_{MB}$ by letting $\mathbf{I}_{MB}(m,n) = \mathbf{I}_B(m,n) | \forall m, \forall n$, where $\forall m, \forall n$ means all m and all n. Denote an eraser window **732** by W. Exemplary width and height of the eraser window W (**732**) are 3w, where w is the average width of lines **706**. To determine if a one-valued pixel at location (m, n) of the image $\mathbf{I}_{MB}$ belongs to crease features such as lines **706**, center the eraser window W **732** at the location (m, n) **728** of $\mathbf{I}_S$ (in operation, the window W is also centered at the location (m, n) **728** of $\mathbf{I}_{MB}$).

In general, there are various types of patterns of the geometry relationship between the window W (**732**) and the one-valued pixels that belong to crease features such as lines **706**. Four exemplary representations of patterns are shown in Fig. 8 assuming window W **732** is centered at location (m,n) **728**. The process of detecting crease features is to look for these patterns in the threshold image. In a north-south pattern **804**, there are zero-valued pixels above and below line **706**. In an east-west pattern **802**, there are zero-valued pixels left and right to line **706**. In a north west-south east pattern **806**, there are zero-valued pixels in the upper left and lower right portions of window W (**732**). In a north east-south west pattern **808**, there are zero-valued pixels in the lower left and upper right portions of window W (**732**).

When pattern **802** occurs, pixel $\mathbf{I}_{MB}(m,n)$ and its associated east-west neighboring one-valued pixels are erased. When pattern **804** occurs, pixel $\mathbf{I}_{MB}(m,n)$ and its associated north-south neighboring one-valued pixels are erased. When pattern **806** occurs, pixel $\mathbf{I}_{MB}(m,n)$ and its associated north west-south east neighboring one-valued pixels are erased. When pattern **808** occurs, pixel $\mathbf{I}_{MB}(m,n)$ and its associated north east-south west neighboring one-valued pixels are erased.

The operation of erosion can be described by the following code:

for m = 0; m < M; m++

```
for n = 0; n < N; n++
    if ( I_S(m,n) == 1)
        center W at I_MB(m,n)
            if (any one of the patterns (802, 804, 806, 808) occurs)

                erase I_MB(m,n) and its associated neighboring pixels;
            end
        end
    end
end
```

Note that the above erosion operation produces an intermediate mask B image, $\mathbf{I}_{MB}$, **902** shown in Fig 9A. There may exist residual elements such as tiny regions **906** in Fig. 9A. They can be further eliminated by checking the sizes after clustering the one-valued pixels in $\mathbf{I}_{MB}$.

Those skilled in the art should understand that alternative erasing methods exist. For example, erasing operation can be implemented without performing medial axis transformation by checking more pixels.

Now referring to Fig. 6, there is a flow chart illustrating the steps of image adjustment. One-valued pixels in the mask B image $\mathbf{I}_{MB}$ are referred to as foreground pixels. Foreground pixels are grouped to form clusters. A cluster is a non-empty set of one-valued pixels with the property that any pixel within the cluster is also within a predefined distance to another one-valued pixel in the cluster. The present invention groups binary pixels into clusters based upon this definition of a cluster. However, it will be understood that pixels may be clustered on the basis of other criteria.

A cluster may be eliminated if it contains too few one-valued pixels no matter it is a cluster of pixels of crease features or a cluster of pixels of an under exposure region. A cluster contains too few one-valued pixels suggests that the cluster does not have much influence on diagnosis. For example, if the number of pixels in a cluster is less than V, then this cluster is erased from $\mathbf{I}_{MB}$.

Example V value could be 10. The above operations are done in a step of Mask property check **602**. A query step **604** branches the process to stop **606** if there are no qualified clusters in mask B $\mathbf{I}_{MB}$, or to step **610** if there is at least on qualified cluster. An exemplary qualified mask B $\mathbf{I}_{MB}$ **912** is shown in Fig. 9B.

Mask B $\mathbf{I}_{MB}$ **912** is now ready to assist applying image adjustment to image **I (501)** in step **510**. Image adjustment is further detailed by steps **610** and **612**.

The exposure correction is accomplished in step **610**. First, denote an image adjustment process by $\Phi(\bullet)$. Denote an adjusted image by $\mathbf{I}_{adj}$. The adjusted image by $\mathbf{I}_{adj}$ can be obtained by the following equation:

$$\mathbf{I}_{adj} = (\mathbf{I} \cap \bar{\mathbf{I}}_{MB}) \cup \Phi(\mathbf{I} \cap \mathbf{I}_{MB}) \qquad (2)$$

where $\bar{\mathbf{I}}_{MB}$ is the logical inverse of $\mathbf{I}_{MB}$, symbol $\cup$ is a logic OR operator, and symbol $\cap$ is a logic AND operator. The operation $(\mathbf{I} \cap \mathbf{I}_{MB})$ signifies that the adjustment process $\Phi(\bullet)$ applies to pixels within region **704** in image **I (501)**. On the other hand, the operation $(\mathbf{I} \cap \bar{\mathbf{I}}_{MB})$ signifies that the pixels outside the region **704** in image **I (501)** keep their original value in this stage.

An exemplary of a preferred algorithm of the present invention for the adjustment process $\Phi(\bullet)$ is described below:

```
structure stats statsB
statsB = F(I ∩ I_MB)
cf = statsA.median/statsB.median;
for (m = 0; m < M; m++)
{
    for (n = 0; n < N; n++)
    {
        if (I_MB(m,n) == 1)
        {
            Ĩ_adj(m,n) = cf·I(m,n);
            if (Ĩ_adj(m,n) > statsA.maximum)
```

{

$\tilde{\mathbf{I}}_{adj}(m,n) = \textbf{\textit{statsA}}.\text{maximum};$

}

}

}

}

$\mathbf{I}_{adj} = (\mathbf{I} \cap \bar{\mathbf{I}}_{MB}) \cup \tilde{\mathbf{I}}_{adj}$.

Note that in the above implementation, the adjustment coefficient *cf* is guaranteed to be greater than or equal to one since $statsA = F(\mathbf{I} \cap \bar{\mathbf{I}}_{MA})$ and $(\mathbf{I} \cap \bar{\mathbf{I}}_{MA})$ contains pixels having intensity greater than or equal to T (**505**), where $T = mean(\mathbf{I}) - K * std(\mathbf{I})$. On the other hand, $statsB = F(\mathbf{I} \cap \mathbf{I}_{MB})$ and $(\mathbf{I} \cap \mathbf{I}_{MB})$ contains pixels having intensity less than (**505**).

Notice also that statistics other than median could be used to compute the adjustment coefficient *cf*, and the adjustment could be applied to individual color channels, (R, G and B), independently. The adjustment operation, $\tilde{\mathbf{I}}_{adj}(m,n) = cf\mathbf{I}(m,n)$, in this embodiment is a linear function. But other types of nonlinear functions such as log adjustment or LUT (look up table) also can be used.

Since the exposure correction is conducted only in areas such as **504** in image **I** (**501**), intensity discontinuity between the exposure corrected (adjustment) and uncorrected (non-adjustment) areas may exist along the boundary line such **1004** in Fig. 10A. Line **1004** separates region **904** (same as **504**) from the rest of the image. To smooth out intensity discontinuity, a step of Cross boundary smoothing **612** follows the step of Exposure correction in masked area(s) **610.**

In Fig. 10A, two lines, two non-intersecting lines **1006** and **1008** define an intensity smoothing band. Lines **1006** and **1008** are on either side of a boundary line **1004** in relation to adjustment and non-adjustment areas for the in vivo image. Lines **1006** and **1008** are formed with respect to line **1004** with a

certain distance at each point to form the band width. An exemplary distance is a constant distant *d* **(1012)**. An exemplary process of forming lines **1006** and **1008** is illustrated as follows. Select a point **1020** on line **1004**. Find the tangent arrow **1014** of line **1004** at point **1020**. Find a line **1019** that passes point **1020** and is perpendicular to arrow **1014**. Find a point **1010** on line **1019** with a distance *d* **(1012)** away from point **1020** at one side of line **1004**. Find a point **1018** on line **1019** with a distance *d* **(1012)** away from point **1020** at the other side of line **1004.** Repeating this process for all other points on line **1004** forms two lines **1006** and **1008**.

The cross boundary smoothing operation can be realized in one-dimensional space or two-dimensional space. Fig. 10B displays a one-dimensional realization. Denote point **1020** on line **1019** by x(0), point **1018** by x(-d), and point **1010** by x(d). Other points on line 1019 will be named accordingly in the following code of implementation.

```
for (i = 0; i <= d; i++)
{
    x(i) = 1/(2D+1) Σ_{-D}^{D} x(i+j);
}
for (i = -1; i >= -d; i--)
{
    x(i) = 1/(2D+1) Σ_{-D}^{D} x(i+j);
}
```

D is less than or equal to *d*. Exemplary value for *D* is 1, and 10 for *d*.

From the above code, it can be seen that the new x(0) is the moving average of pixels from both sides of the boundary line **1014**. The influence of pixels from one side to the other side is propagated through newly updated $x(i)$. Starting the process from $x(0)$ helps the propagation of information across the boundary.

The operation described by the above discussion is assumed to be operated in an sRGB space (see Stokes, Anderson, Chandrasekar and Motta, "A Standard Default Color Space for the Internet – sRGB", http://www.color.org/sRGB.html).

Images in sRGB have already been optimally rendered for video display, typically by applying a 3x3 color transformation matrix and then a gamma compensation lookup table. Any adjustment to the brightness, contrast, and gamma characteristics of an sRGB image will degrade the optimal rendering. If a digital image contained pixel values representative of a linear or logarithmic space with respect to the original scene exposures, the pixel values could be adjusted without degrading any subsequent rendering steps. For those skilled in the art, the ideas and algorithms of the present invention can be applied to spaces such as de-rendered logarithmic space.

Fig. 4 shows an exemplary of an examination bundlette processing hardware system useful in practicing the present invention including a template source **400** and an RF receiver **412** (also **308**). The template from the template source **400** is provided to an examination bundlette processor **402**, such as a personal computer, or work station such as a Sun Sparc workstation, or a handheld device (e.g., personal digital assistant—PDA). The RF receiver passes the examination bundlette to the examination bundlette processor **402**. The examination bundlette processor **402** preferably is connected to a CRT display **404** (which may be a touch-screen display), an operator interface such as a keyboard **406** and a mouse **408**. Examination bundlette processor **402** is also connected to computer readable storage medium **407**. The examination bundlette processor **402** transmits processed and adjusted digital images and metadata to an output device **409**. Output device **409** can comprise a hard copy printer, a long-term image storage device, and a connection to another processor. The examination bundlette processor **402** is also linked to a communication link **414** (also **312**) or a telecommunication device connected, for example, to a broadband network.

It is well understood that the transmission of data over wireless links is more prone to requiring the retransmission of data packets than wired links. There is a myriad of reasons for this, a primary one in this situation is that the patient moves to a point in the environment where electromagnetic interference occurs. Consequently, it is preferable that all data from the Examination Bundle be transmitted to a local computer with a wired connection.

This has additional benefits, such as the processing requirements for image analysis are easily met, and the primary role of the data collection device on the patient's belt is not burdened with image analysis. It is reasonable to consider the system to operate as a standard local area network (LAN). The device on the patient's belt **100** is one node on the LAN. The transmission from the device on the patient's belt **100** is initially transmitted to a local node on the LAN enabled to communicate with the portable patient device **100** and a wired communication network. The wireless communication protocol IEEE-802.11, or one of its successors, is implemented for this application. This is the standard wireless communications protocol and is the preferred one here. It is clear that the Examination Bundle is stored locally within the data collection device on the patient's belt, as well at a device in wireless contact with the device on the patient's belt. However, while this is preferred, it will be appreciated that this is not a requirement for the present invention, only a preferred operating situation. The second node on the LAN has fewer limitations than the first node, as it has a virtually unlimited source of power, and weight and physical dimensions are not as restrictive as on the first node. Consequently, it is preferable for the image analysis to be conducted on the second node of the LAN. Another advantage of the second node is that it provides a "back-up" of the image data in case some malfunction occurs during the examination. When this node detects a condition that requires the attention of trained personnel, then this node system transmits to a remote site where trained personnel are present, a description of the condition identified, the patient identification, identifiers for images in the Examination Bundle, and a sequence of pertinent Examination Bundlettes. The trained personnel can request additional images to be transmitted, or for the image stream to be aborted if the alarm is declared a false alarm. Details of requesting and obtaining additional images for further diagnosis can be found in commonly assigned, co-pending U.S. Patent Application Serial No. (our docket 86570SHS), entitled "Method And System For Real-Time Remote Diagnosis Of In Vivo Images" and filed on 01 March 2004 in the names of Shoupu Chen, Lawrence A. Ray, Nathan D. Cahill, and Marvin M. Goodgame, and which is incorporated

herein by reference. To ensure diagnosis accuracy, images to be transmitted are those exposure adjusted in step **309.**

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

PARTS LIST

100 Storage Unit
102 Data Processor
104 Camera
106 Image Transmitter
108 Image Receiver
110 Image Monitor
112 Capsule
200 Examination Bundle
202 Image Packets
204 General Metadata
206 Image Packet
208 Pixel Data
210 Image Specific Metadata
212 Image Specific Collection Data
214 Image Specific Physical Data
216 Inferred Image Specific Data
220 Examination Bundlette
300 In Vivo Imaging system
302 In Vivo Image Acquisition
304 Forming Examination Bundlette
306 RF Transmission
308 RF Receiver
309 Image adjustment
310 Abnormality Detection
312 Communication Connection
314 Local Site
316 Remote Site
320 In Vitro Computing Device
400 Template source
402 Examination Bundlette processor

404 Image display

406 Data and command entry device

407 Computer readable storage medium

408 Data and command control device

409 Output device

412 RF transmission

414 Communication link

501 An image

502 Image Thresholding

503 ***Stats***

504 Forming mask B

505 Threshold

506 Forming mask A

508 Image statistics gathering

510 Image adjusting

602 Mask property check

604 A query

606 Stop

610 Exposure correction in masked area(s)

612 Cross boundary smoothing

702 Binary image

704 A region

706 Lines

712 Mask A

722 Skeleton image

724 Lines

726 Lines

728 A point

732 A window

802 A pattern

804 A pattern

806 A pattern

808 A pattern

816 A dark area

822 A generalized R image

902 An intermediate mask B

904 A region

906 Residuals

912 Mask B image

1002 A smoothing band graph

1004 A line

1006 A line

1008 A line

1010 A point

1012 A distance *d*

1014 An arrow

1018 A point

1019 A line

1020 A point